RFID: Measurement and Practice
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Outline

- Universe of RFID
- Passive RFID
- Passive UHF RFID
- Metrics and Measurements
- Research Issues
- State of the Art

- Ask questions as we go

RFID vs. Barcode

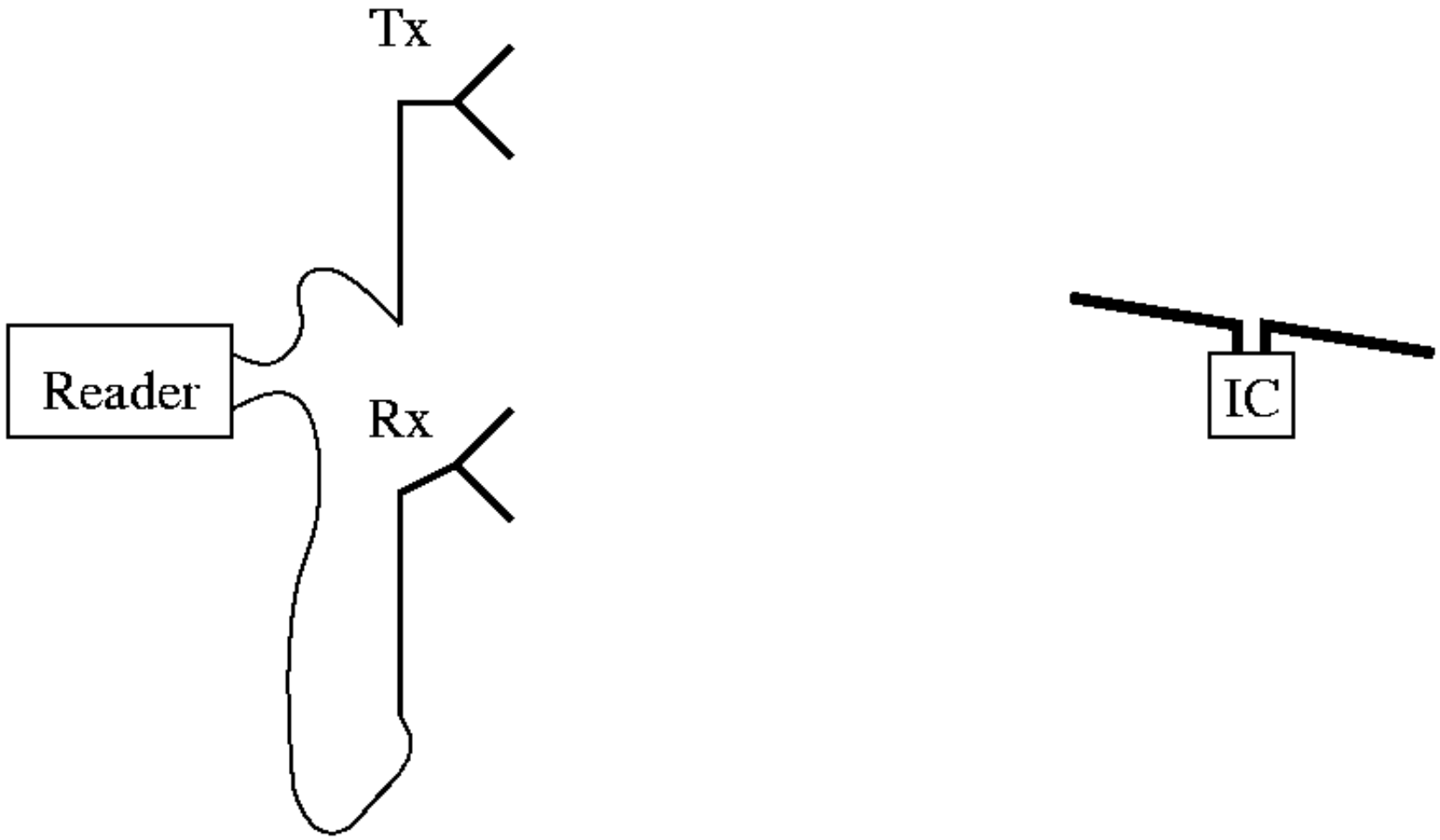
- Bar codes on steroids
  - Simultaneous identification
  - Non line-of-Sight
  - Data storage
  - Read/write
  - Durability
  - Difficult to replicate
- UHF Passive
  - Inexpensive
  - Performance
  - Leverage infrastructure
  - Lifespan

The EPC Mandates & Recommendations

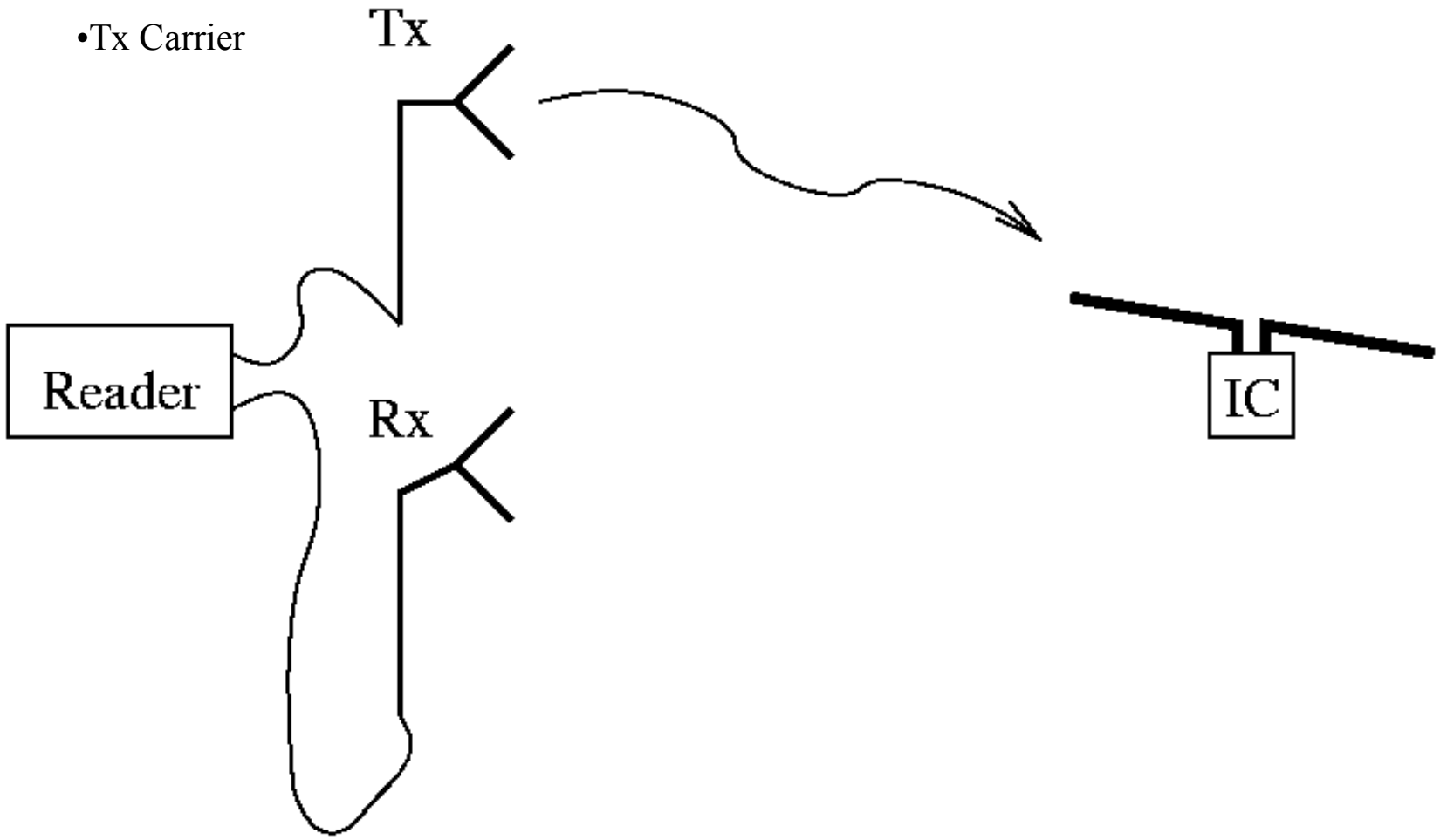
Brief Universe of RFID

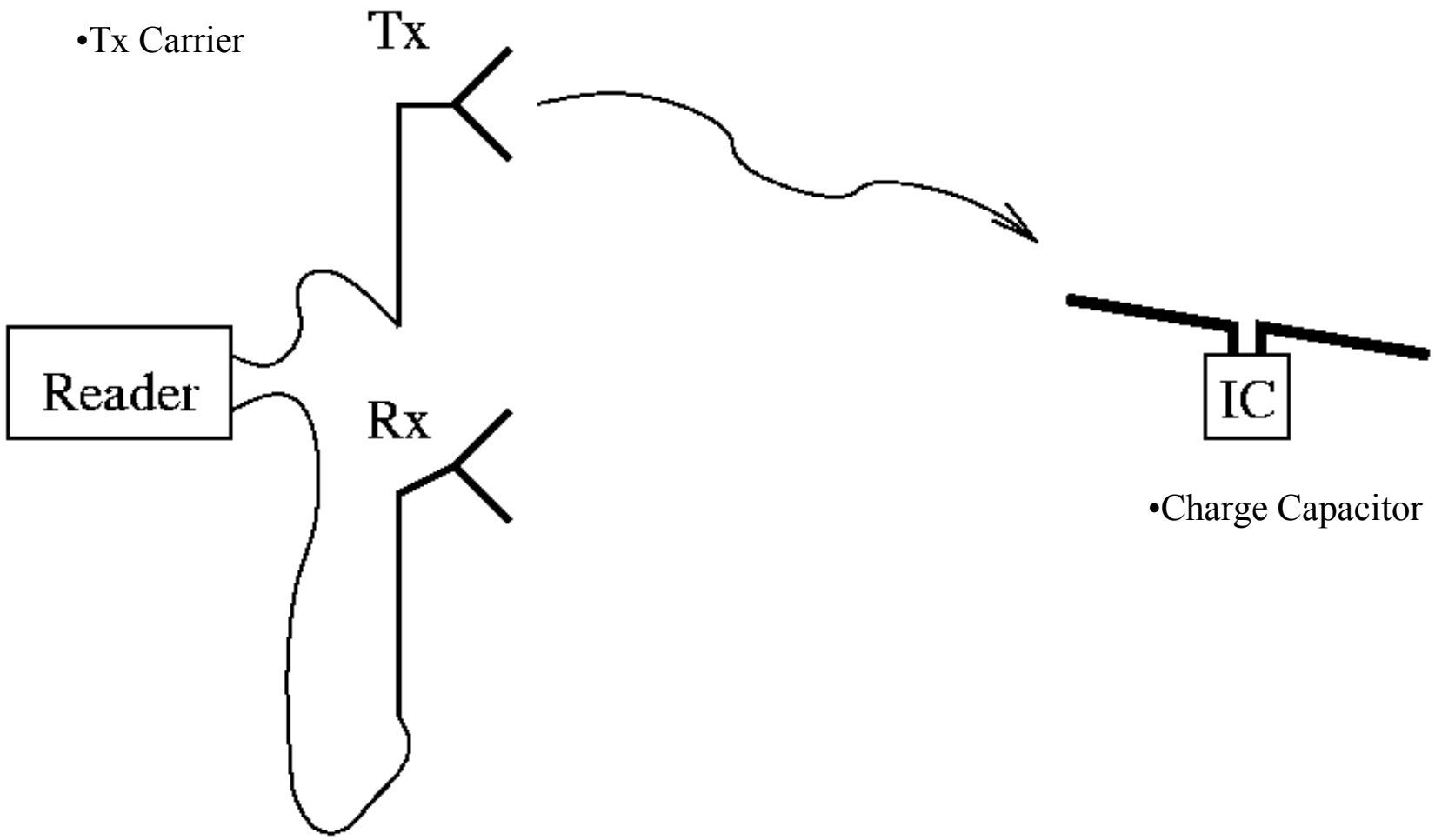
- Chip / Chipless
- Power
  - Active
  - Battery-assist
  - Passive
- Frequency
  - LF: 125 or 135 KHz
  - HF: 13.56 MHz
  - UHF: 433 MHz (active), 915 MHz (passive)
  - Microwave: 2.4 GHz, 5.8 GHz, etc.

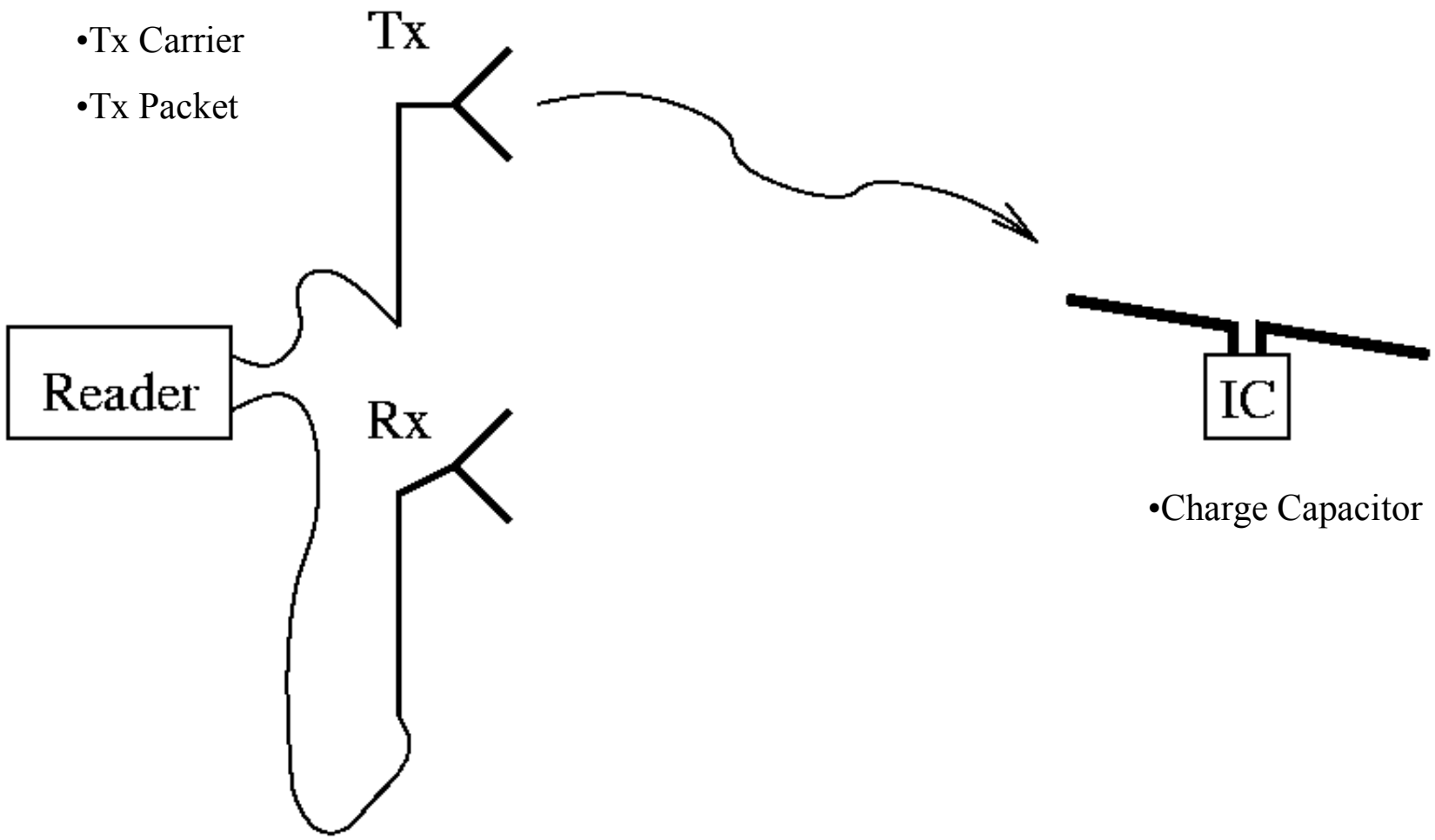
How UHF RFID Works (briefly)

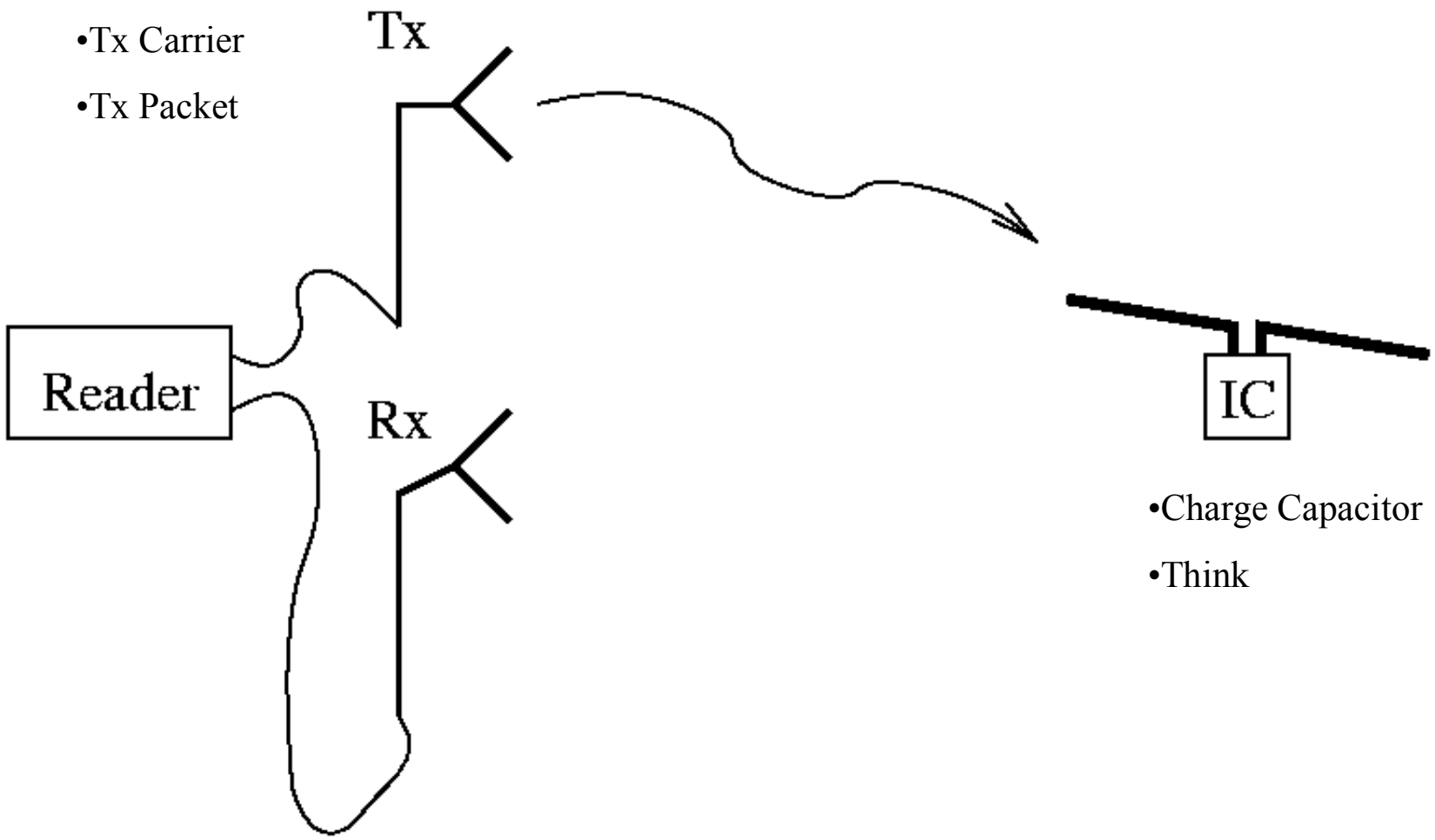


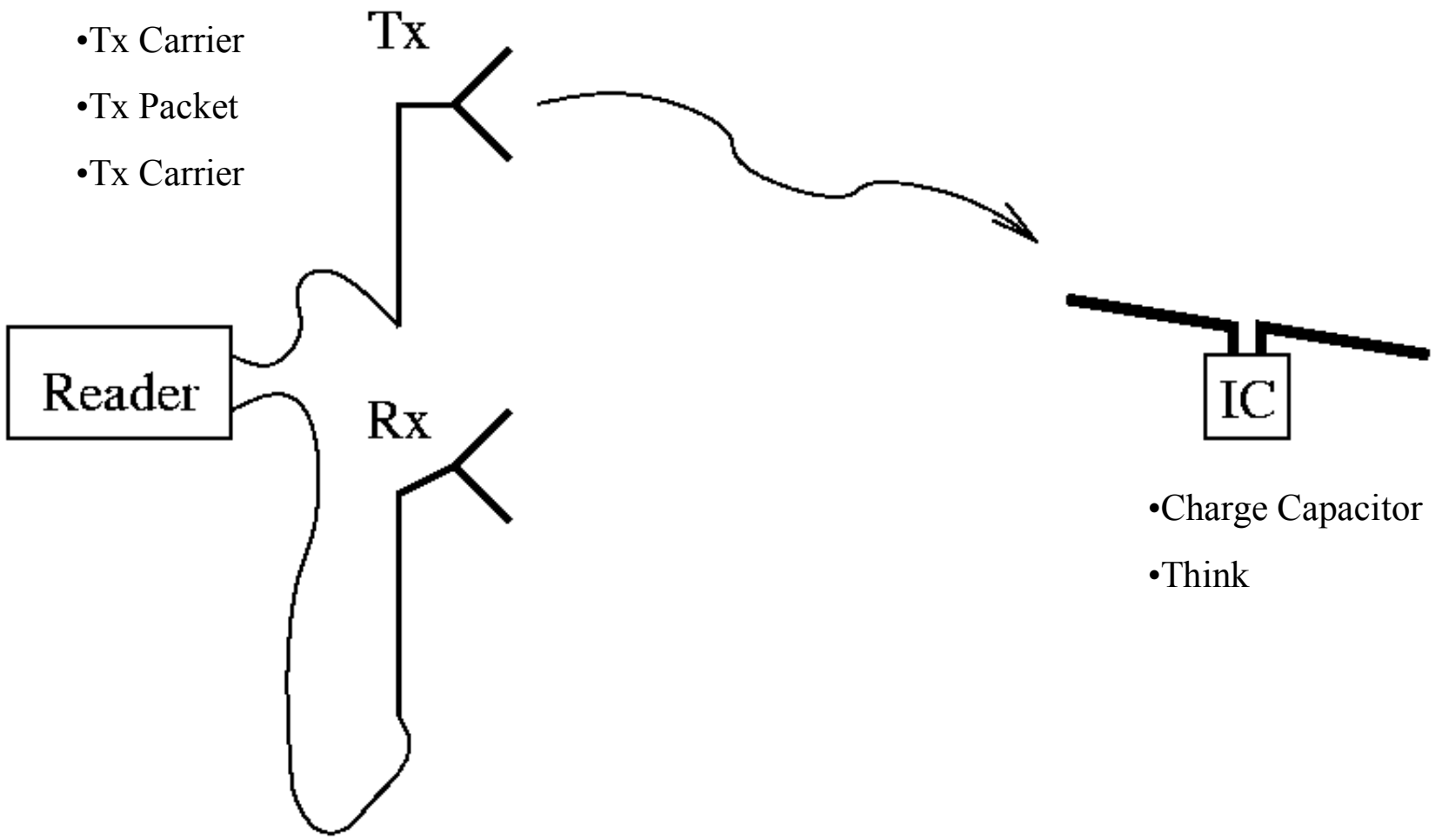
•Tx Carrier

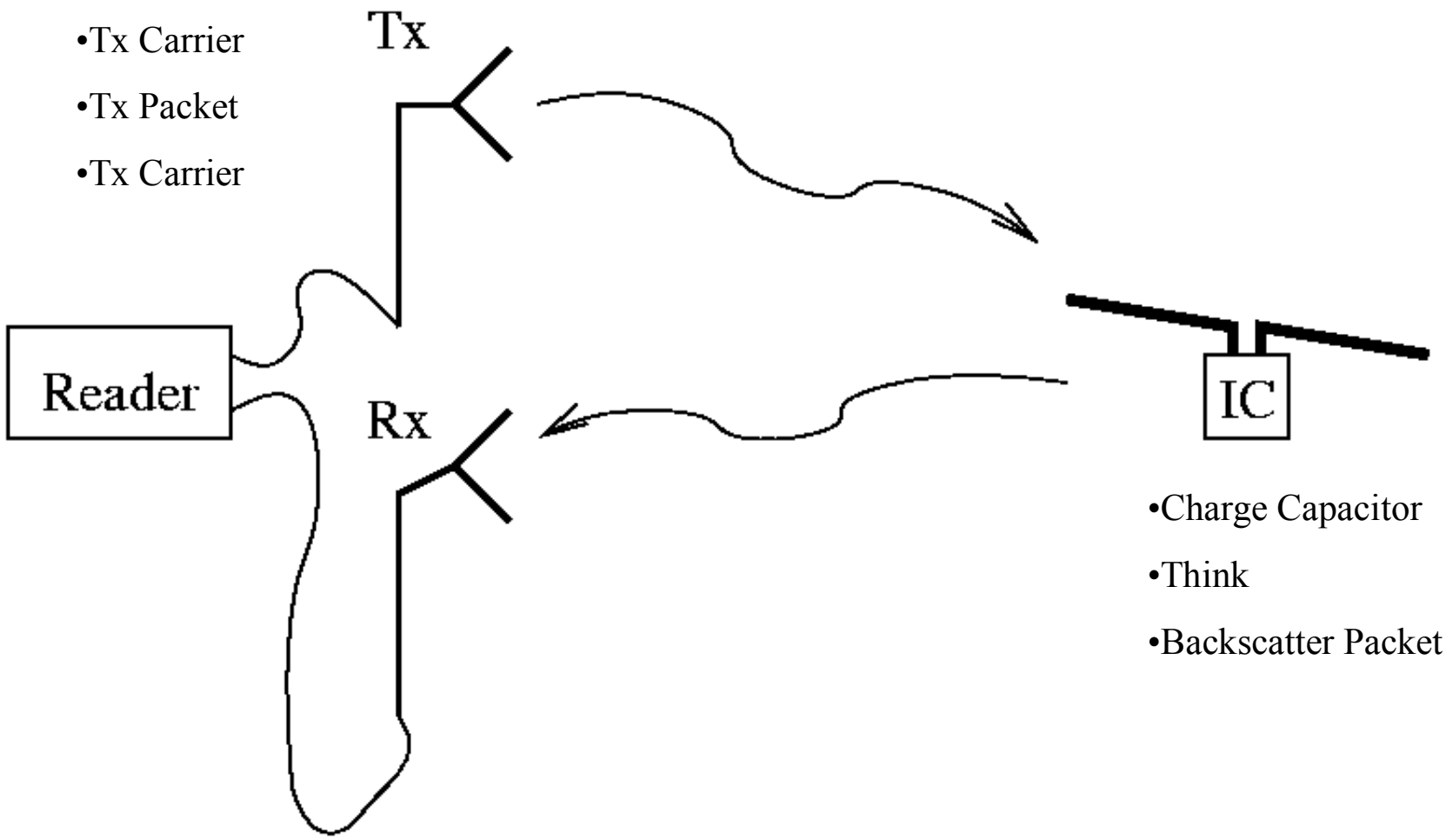





•Tx Carrier
•Tx Packet
Tx
Reader
Rx
IC
•Charge Capacitor

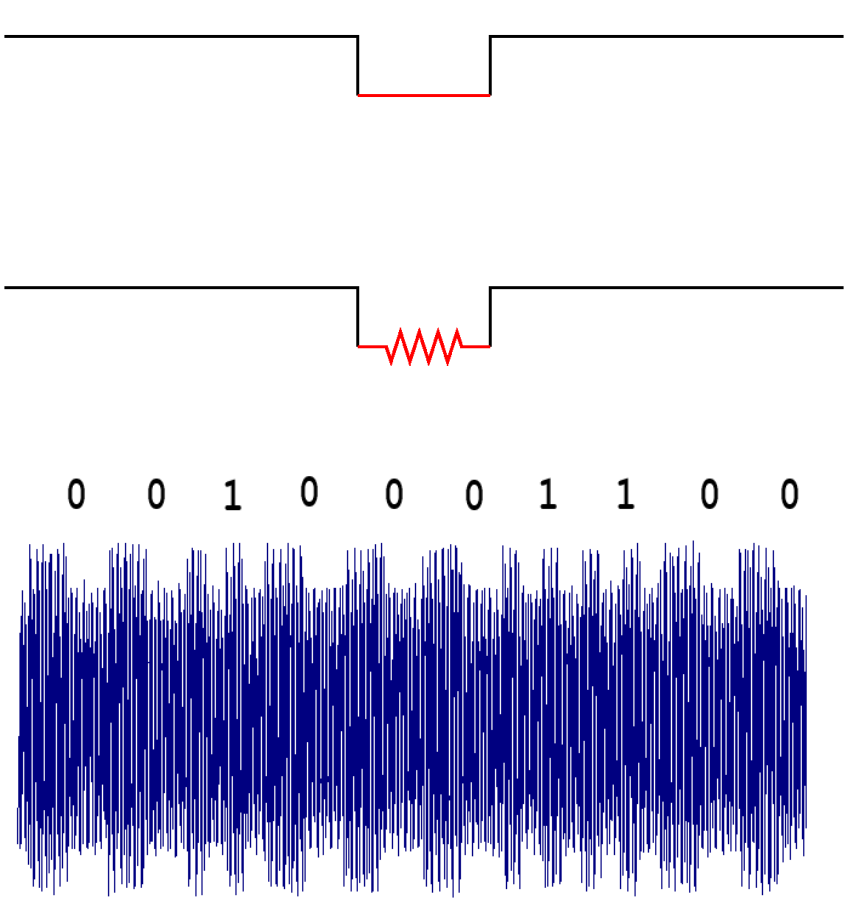

•Tx Carrier
•Tx Packet
Tx
Reader
Rx
IC
•Charge Capacitor
•Think


•Tx Carrier
•Tx Packet
•Tx Carrier
Tx
Reader
Rx
IC
•Charge Capacitor
•Think


•Tx Carrier
•Tx Packet
•Tx Carrier
Tx
Reader
Rx
IC
•Charge Capacitor
•Think
•Backscatter Packet

Backscatter Modulation

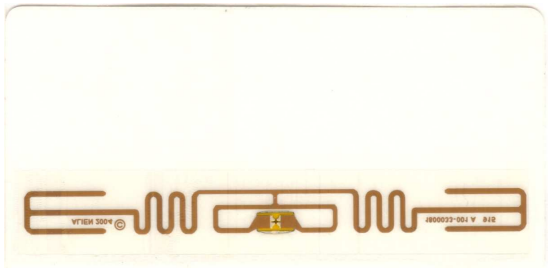
- Tag modulates RCS
- Short (or open):
  - large RCS
- Matched load:
  - power → heat
  - smaller RCS
- Binary modulate RCS over time
  - ASK, FSK, etc.



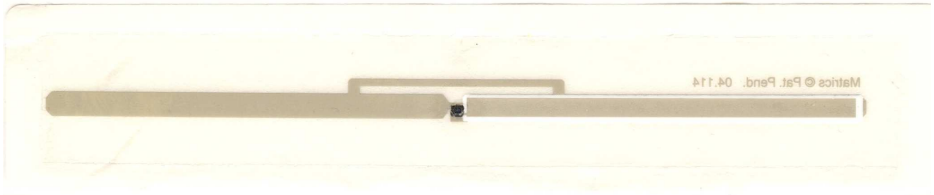
LF/HF Technologies

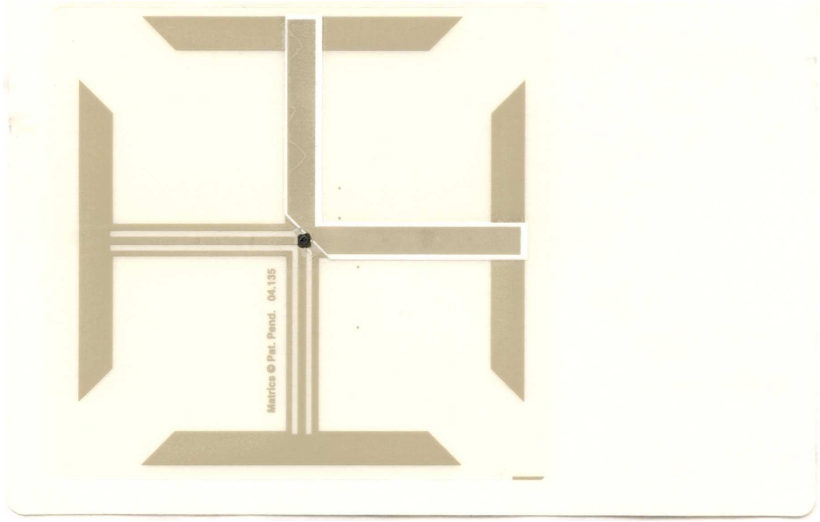
- Power and communicate via coupling
  - Near-field communication
  - Power proportional to d^3
- Inductive coupling
  - Two loop antennas
  - Overlapping near fields
- Capacitive coupling
- Reduced sensitivity to environment
  - Ferrite cores → embed *in* metal surfaces
  - LF embeds under skin (inside water)

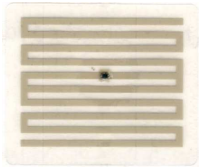
Alien UHF Tags

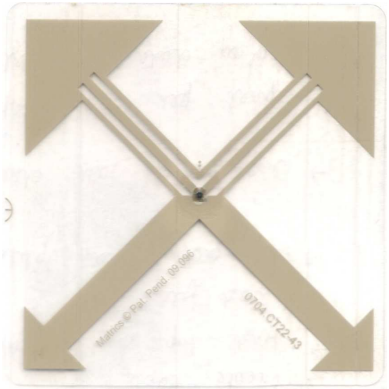


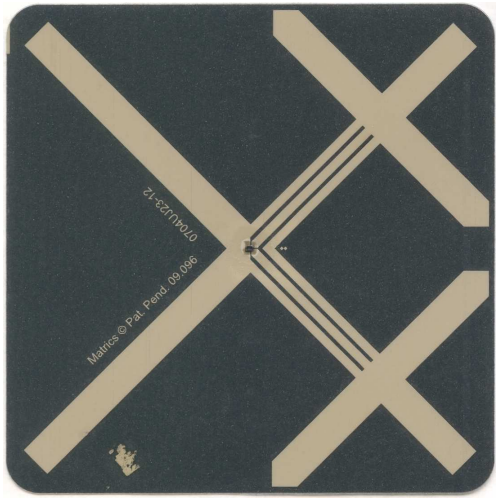
Symbol Dipole Tags



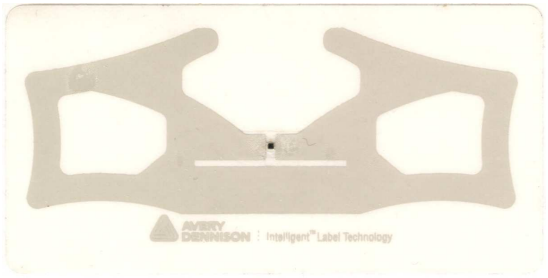


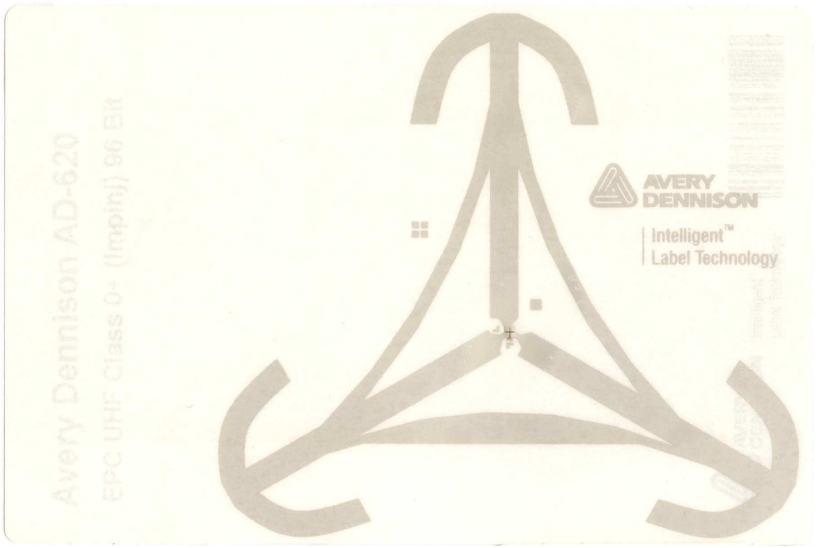


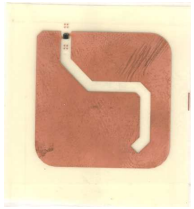


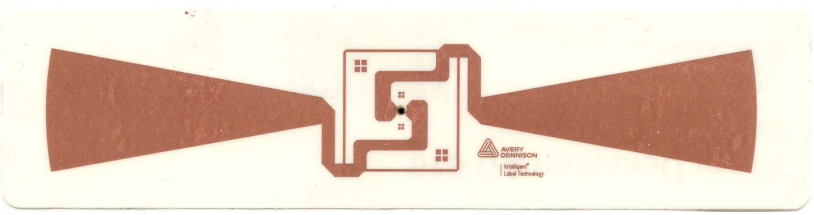


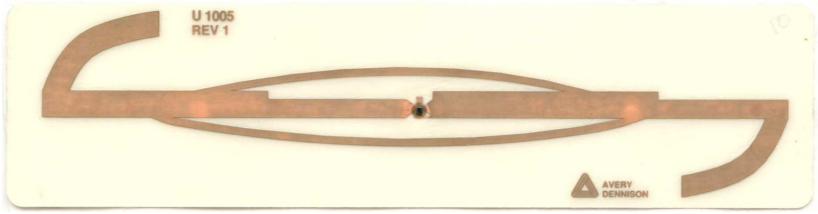
Avery Dennison Tags



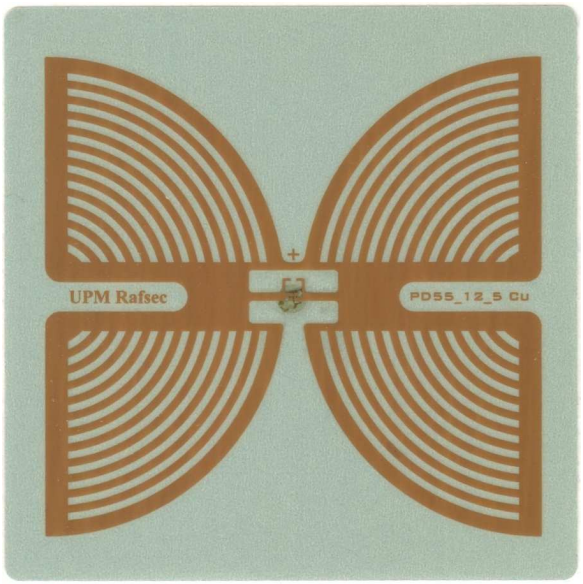


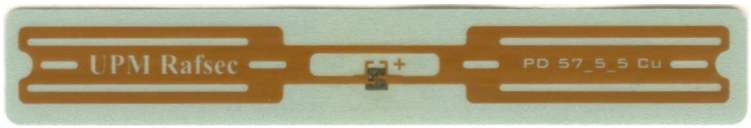


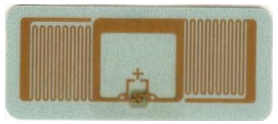




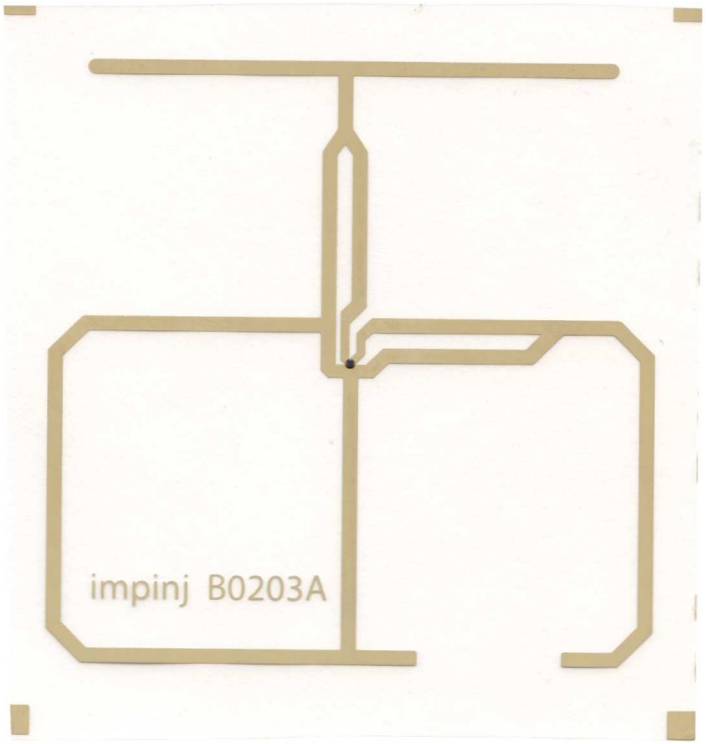
Rafsec Tags

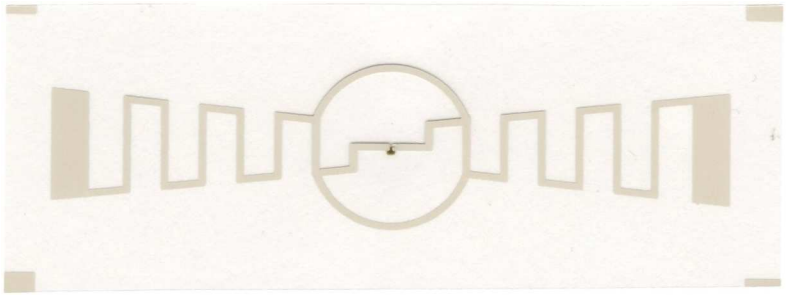


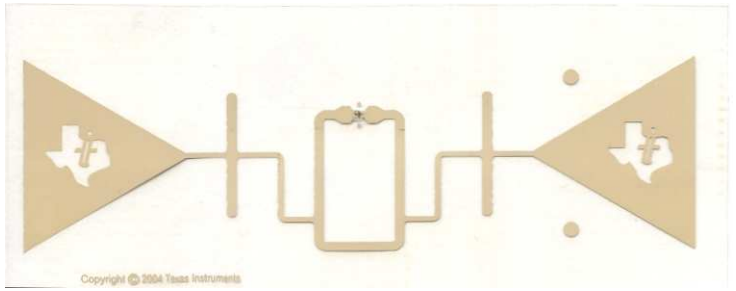




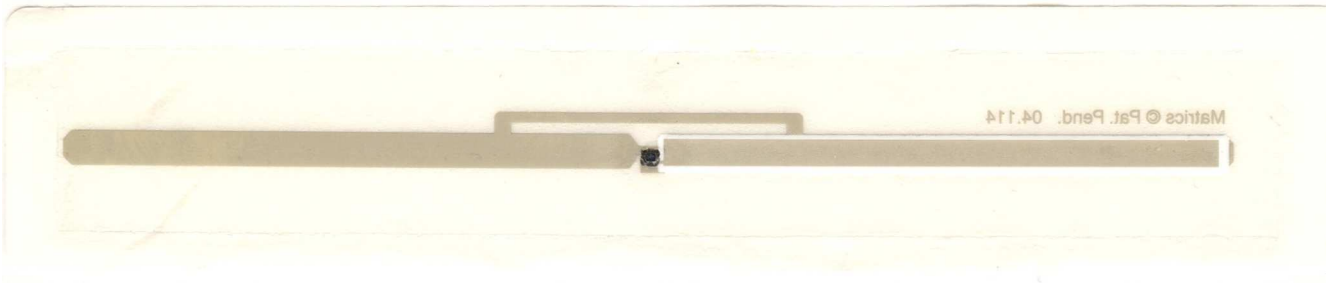
ASK, Precisia, TI tags





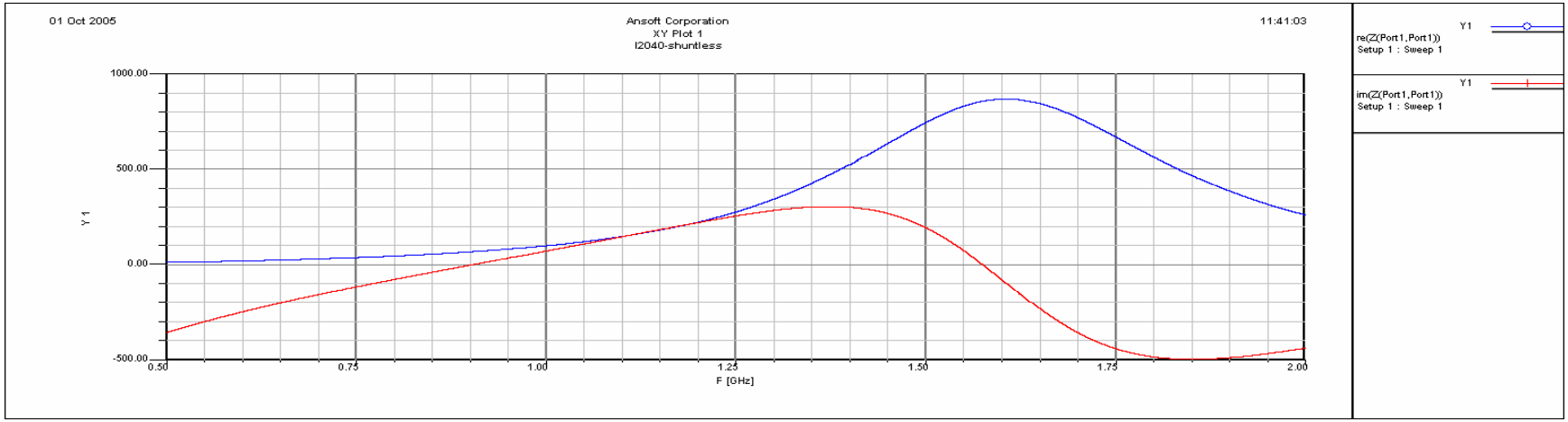


Why do tags look the way they do?

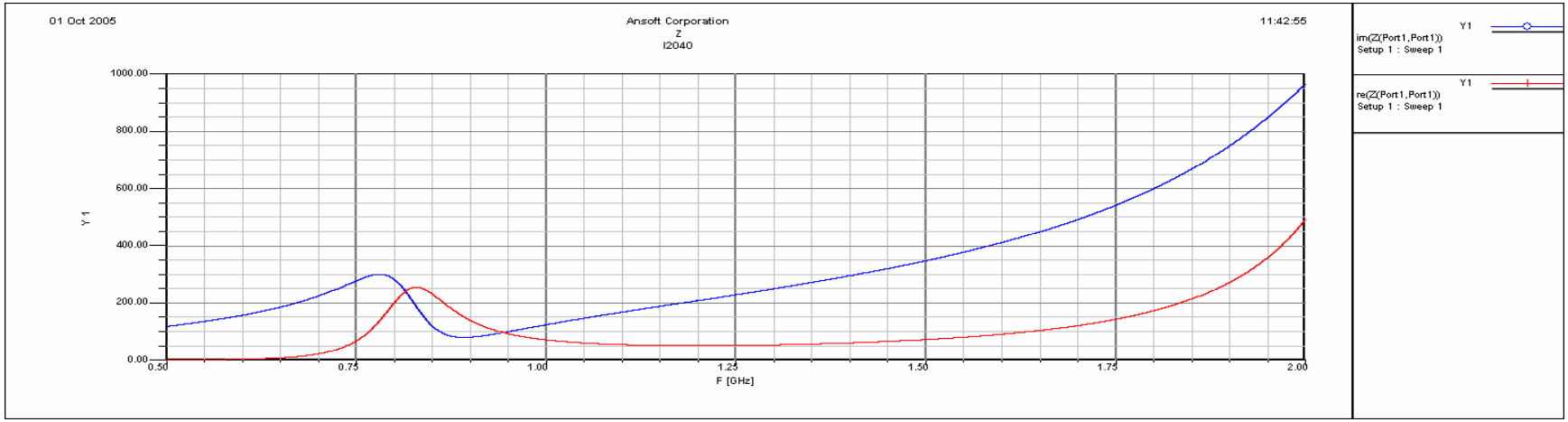


- Impedance of chip is highly reactive, e.g., 6.7-j197.4Ω.
- Effort put into matching circuit
  - Minimize change in impedance when put on dielectrics
  - Commonly use shorting stubs

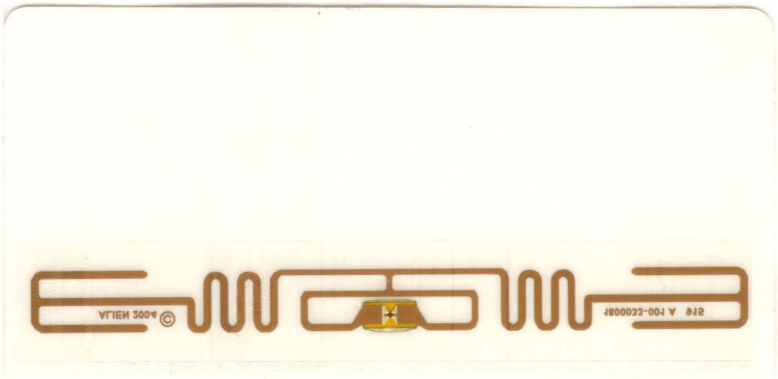
Impedance Without Stub

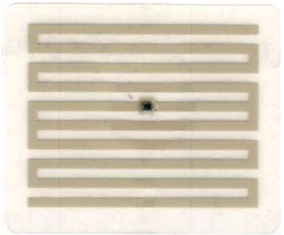


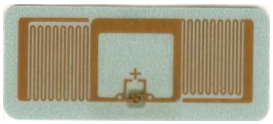
Impedance With Stub

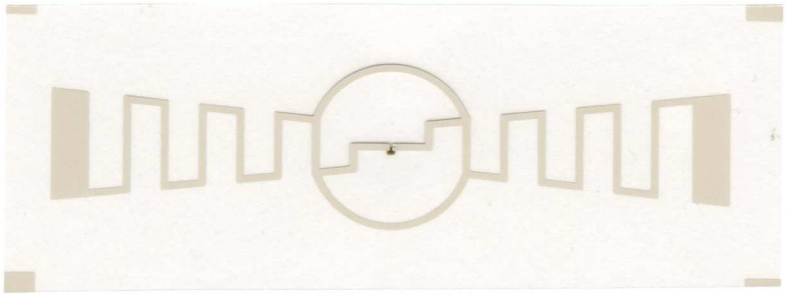


Meanderings, folds

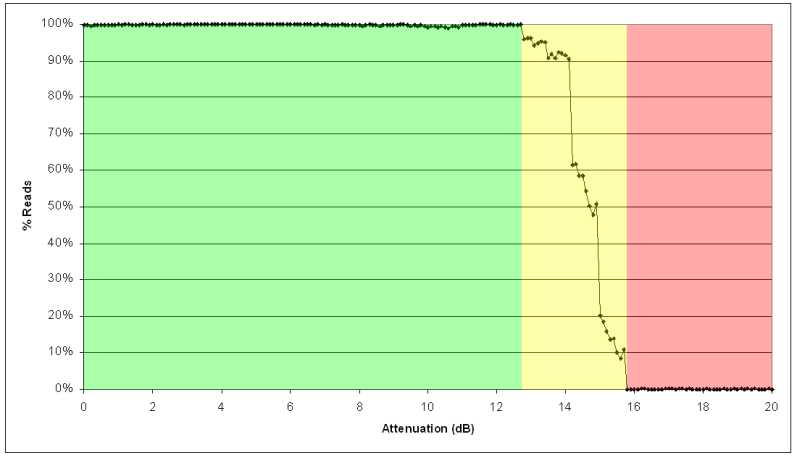


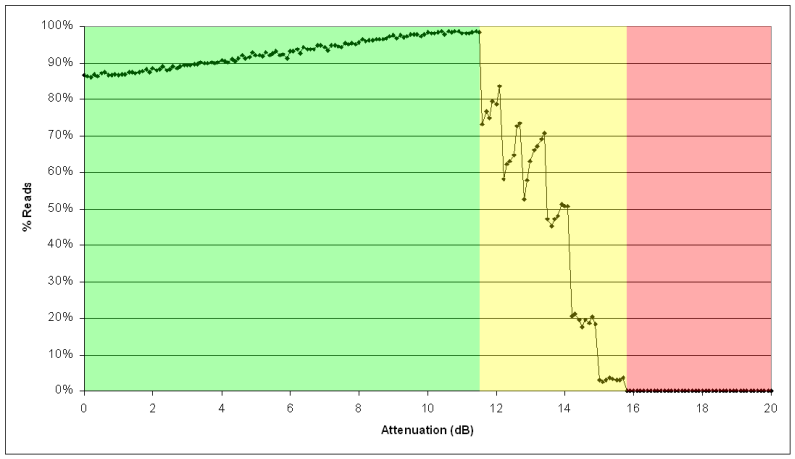






Tag Performance vs. Distance

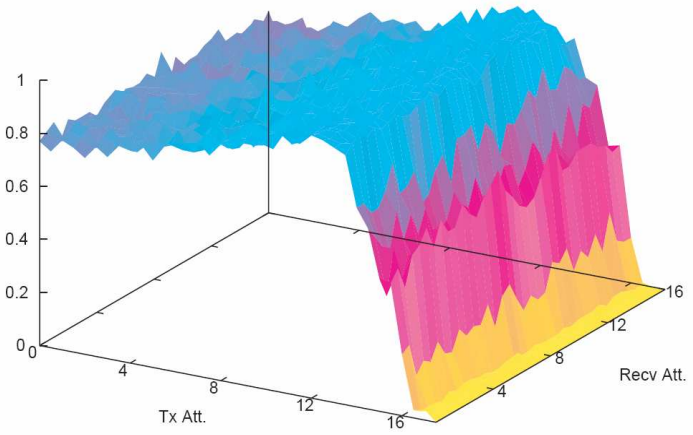


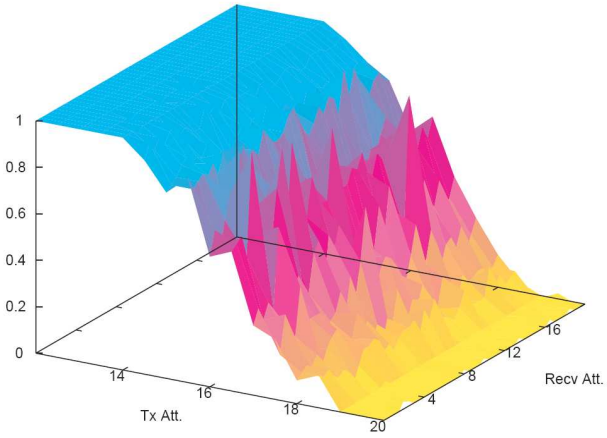


- Typical Class 0, 1 percent reads vs. attenuation (distance)
- Strong in-field, ~0-15’
  - 100% vs 85-99%
- Weak in-field, ~15-20’
  - Bumpy ride down
- Out of field, ~20’+
  - 0 vs 0.13% “phantom” reads for Class 0

Link Margins for “Large” Tags

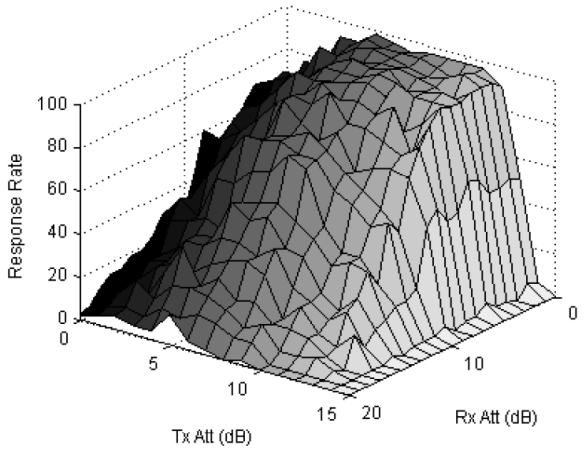
- Attenuate Tx, Rx lines independently
- For two “large” tags: Class 0, 1
- Observe:
  - Performance completely independent of reverse link
- Large tags are strongly forward-link limited

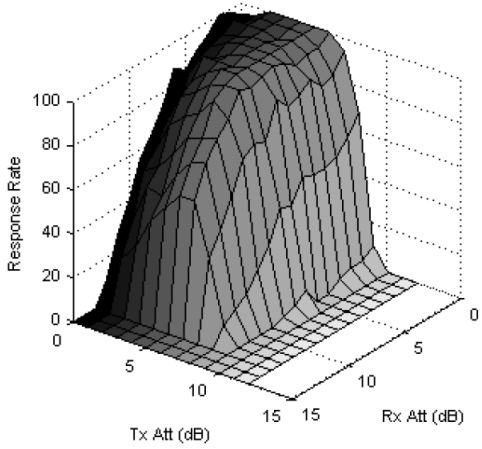




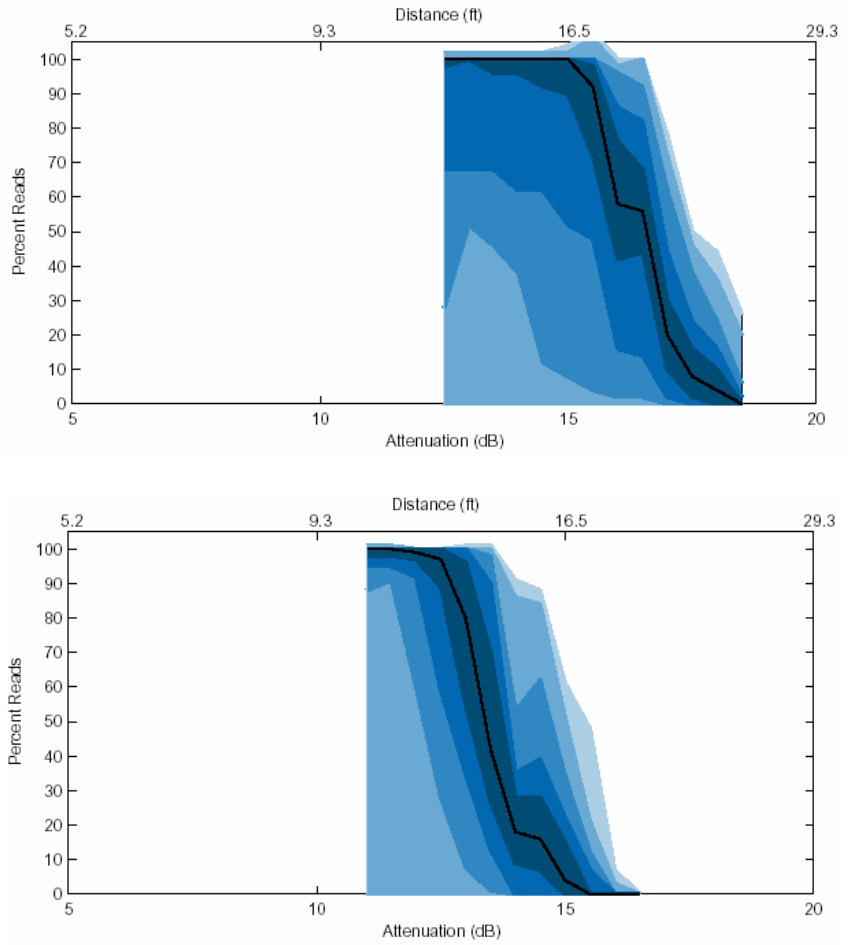
Link Margins for “Small” Tags

- Attenuate Tx, Rx lines independently
- For two “small” tags: Class 0, 1
- Observe:
  - Performance degrades noticeably with small Rx attenuation
- Small tags are balanced





Tag Variation — The Bad News

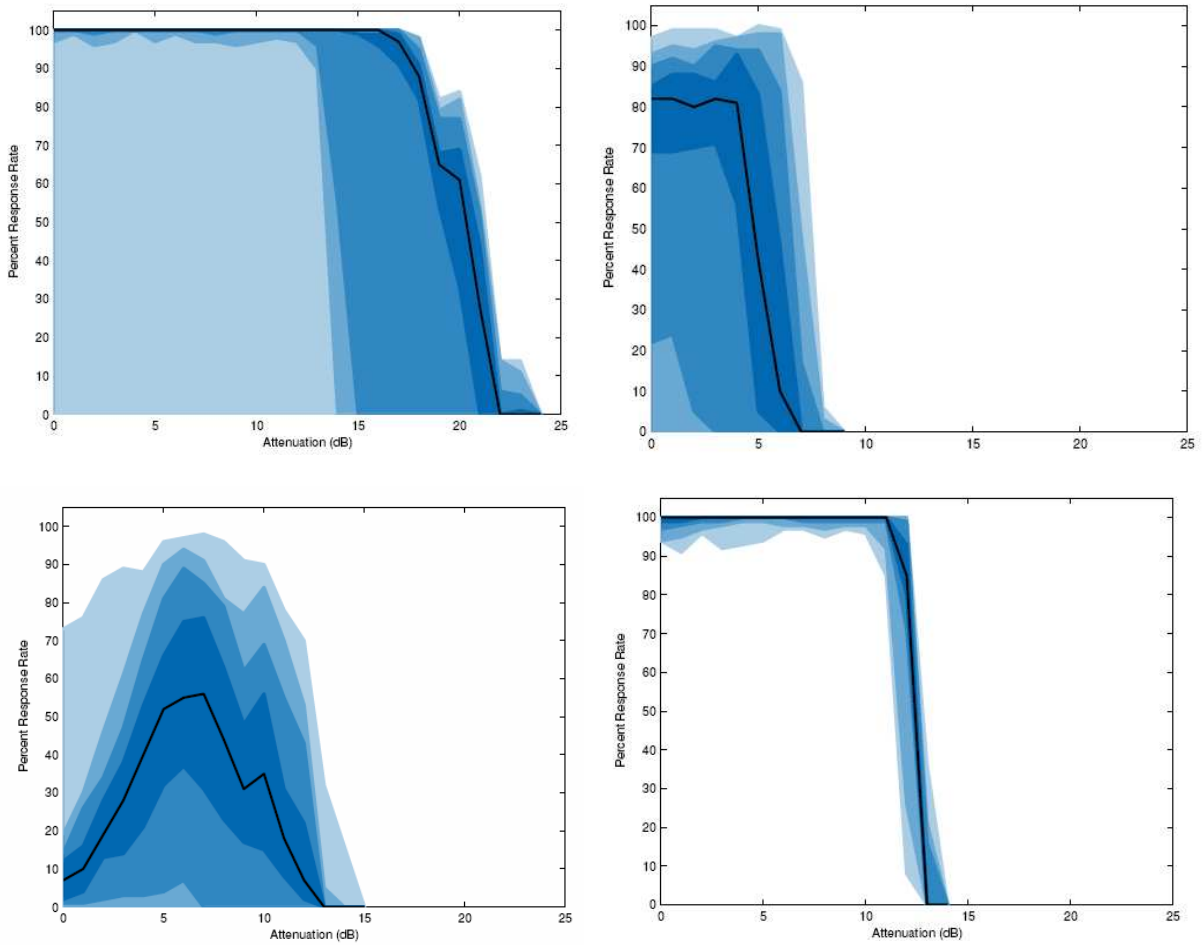


- Tags vary in performance
  - Model to model
  - Tag to tag
- Narrow bands = high quality
- Far right = high performance

Range	Lower Bound	Upper Bound	% Included
Black	50%	50%	1 tag
Darkest	30%	70%	40%
	15%	85%	70%
	6.5%	93.5%	87%
	1%	99%	98%
Lightest	0%	100%	100%

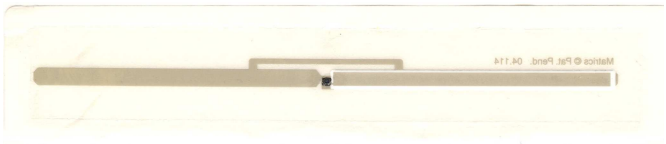
Variance of Item-Level Tags

- Median line
- 30–70%
- 15–85%
- 6.5–93.5%
- 0–100%

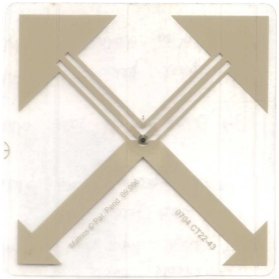


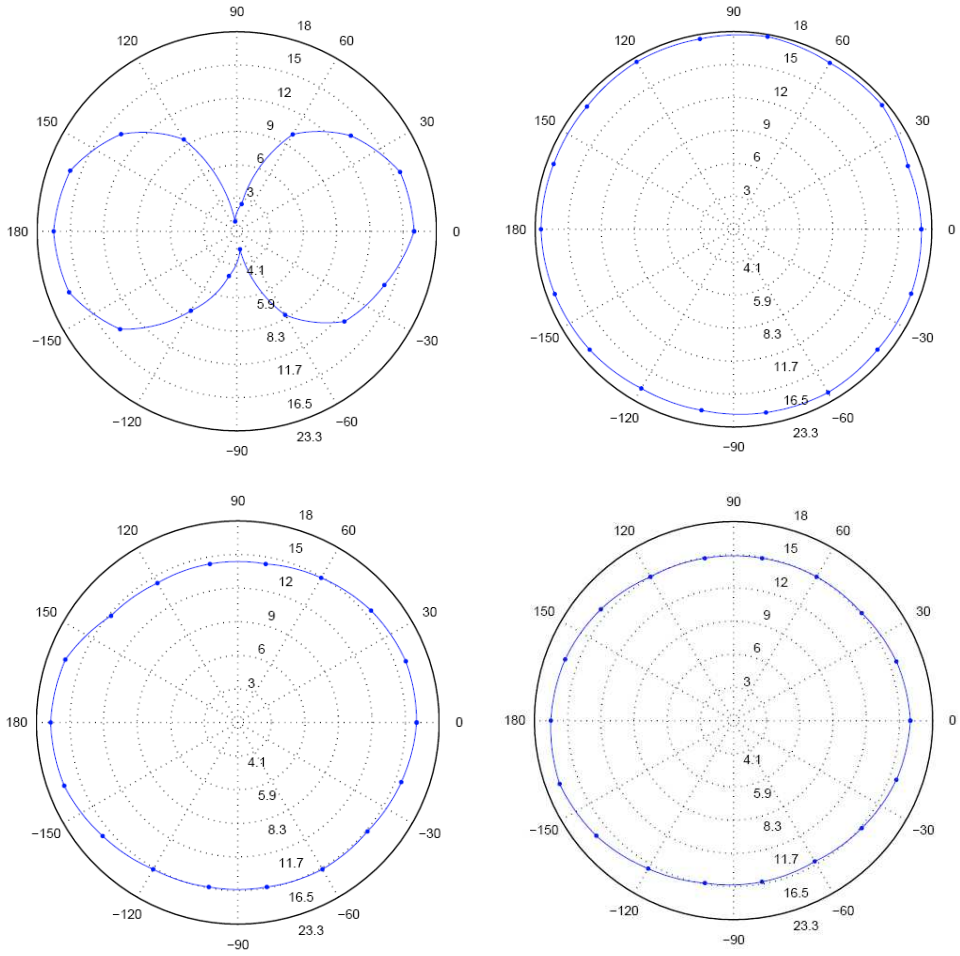
Radiation Patterns

- **Long, narrow tags**
  - Null at “ends” of dipole
  - E.g.,

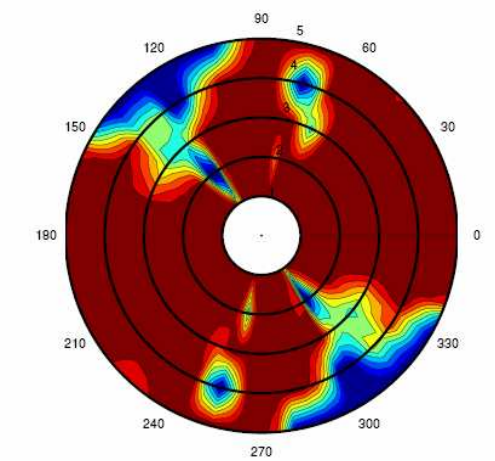


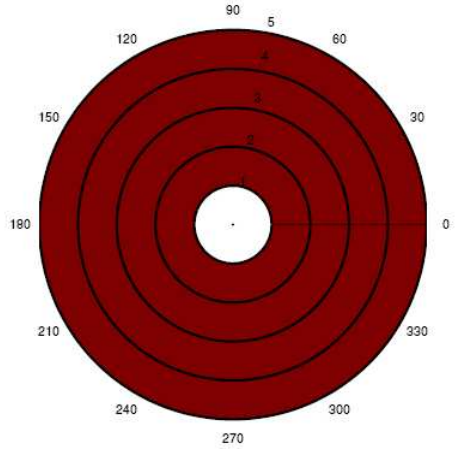
- **Large, square/triangle**
  - Uniform
  - E.g.,





Response Rate vs. Distance, Orientation

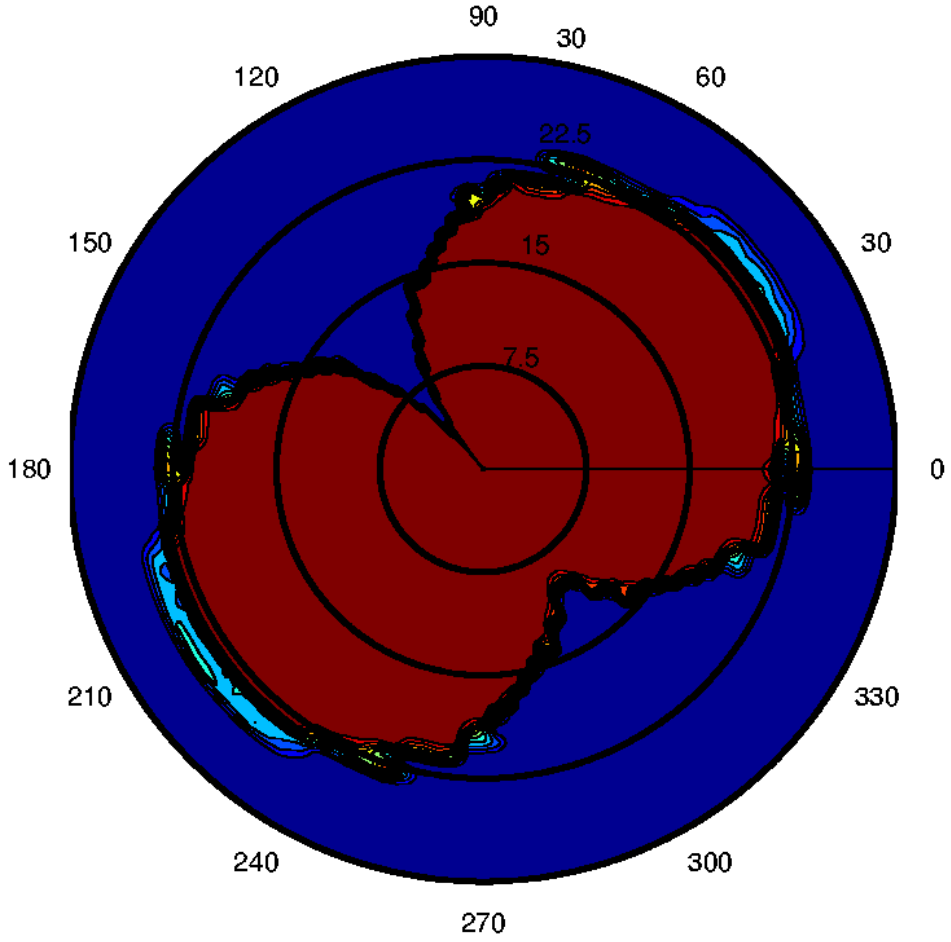




- 2”×2” tag, E- and H-plane
- Reader frequency hopping, 902—928 MHz
- Measured response rate vs. tag angle, distance
- *Highly* symmetric
  - features are real, not random error

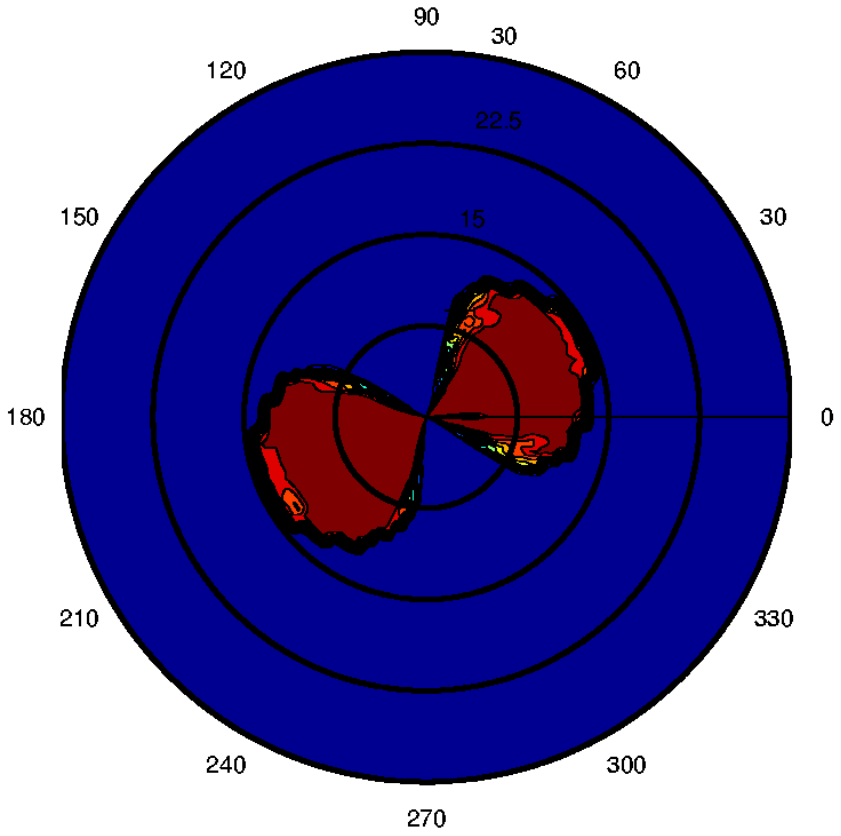
Frequency Dependence Example

- Alien E-plane
  - 902 MHz
  - 907 MHz
  - 912 MHz
  - 918 MHz
  - 923 MHz
  - 928 MHz
  - 953 MHz (butterfly)



Frequency Dependence Example

- Rafsec E-plane
  - 902 MHz
  - 907 MHz
  - 912 MHz
  - 918 MHz
  - 923 MHz
  - 928 MHz
  - 953 MHz (very poor)



Frequency Use

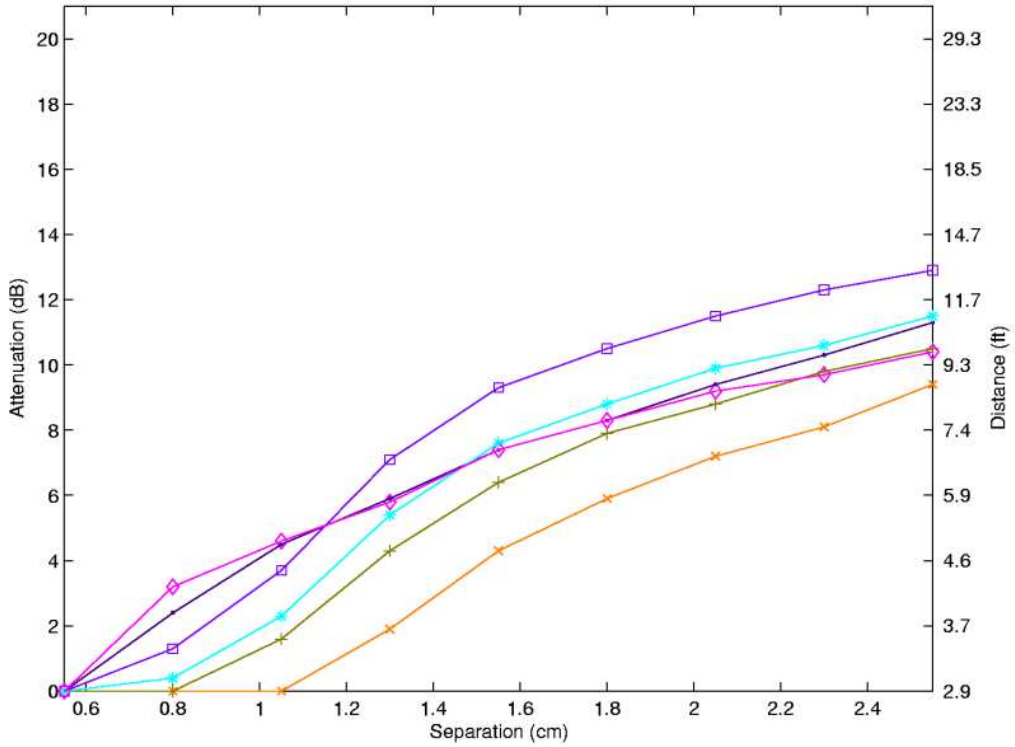
- 865—869 MHz
  - Europe
  - India
- 902—928 MHz
  - North America
- 953 MHz
  - Japan
  - China?
- Smaller countries using, e.g., 880, 940 MHz

- Challenge:
  - Work well over 10% BW
  - In free space
  - On dielectric materials
  - Near conductors
- Reality:
  - Nearly impossible to achieve

Performance of "Large" Class 1 Tags near Water

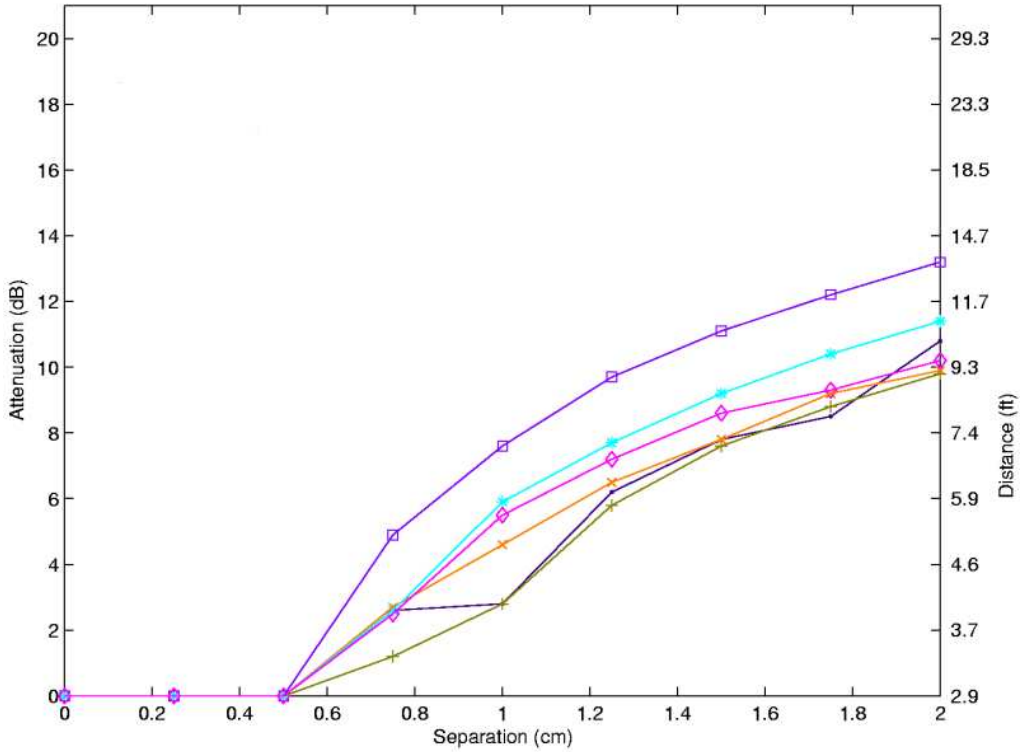
Differences readily apparent

- Pink best close, but shallow slope
- Purple good close, but best further
- Best tag:
  - 150% more efficient than worst
  - 60% further distance
- Some tags are tuned for applications
  - Free air perf. not always fair metric



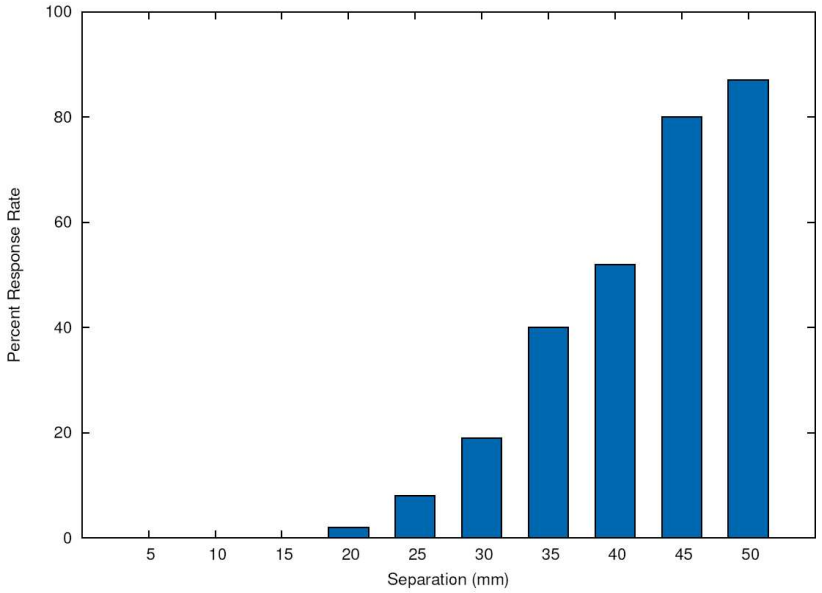
Performance of "Large" Class 1 Tags near Metal

- No tags readable at 5mm
  - "Old" data
  - New tags perform similarly
  - Thickness of cardboard box

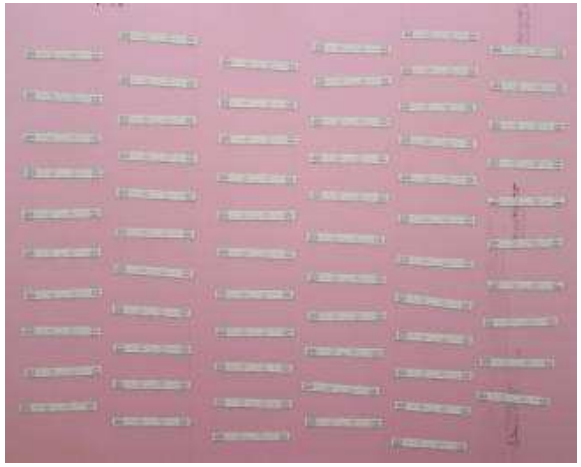


Small Tag Near Metal

- Performance generally degrades drastically near metal, water
  - Practically unusable with tag < 1 inch separation
- New tag that “works well on metal contents”
  - Large, expensive
  - 1m read distance with 8 mm separation
  - ~8m+ distance otherwise

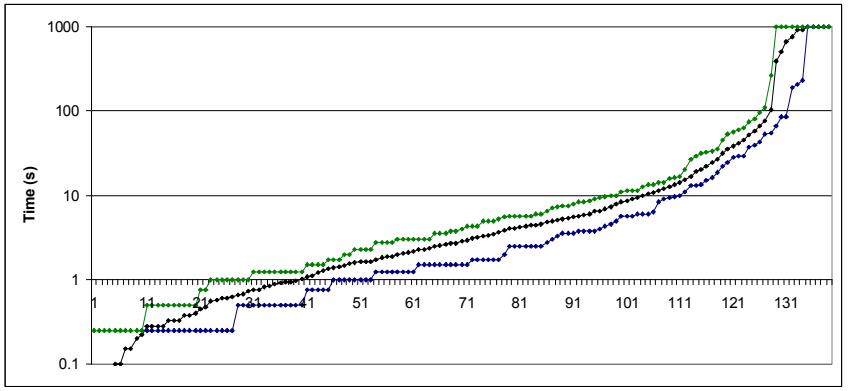


Read Rates in Populations

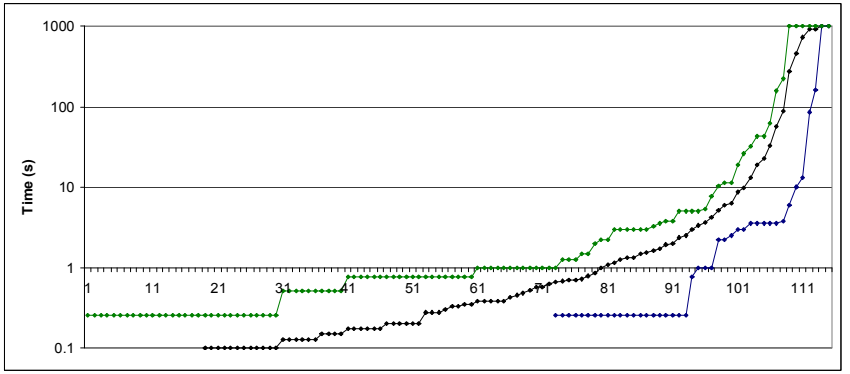


Time to First Read (TTFR)

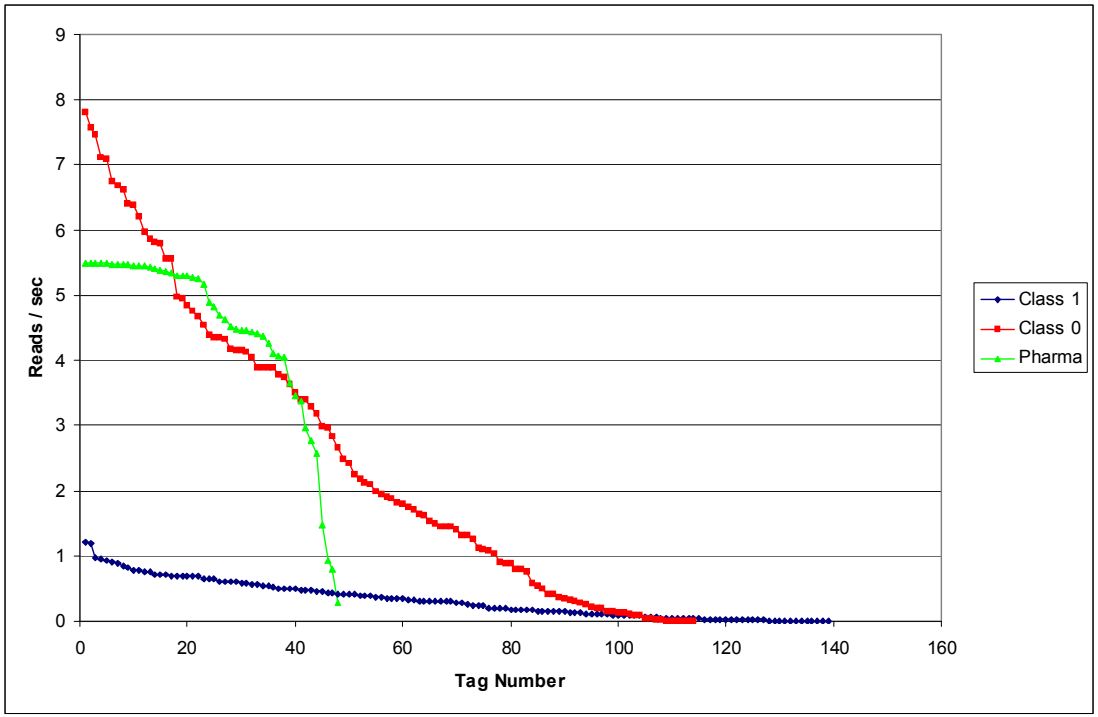
- ~140 Class 1 tags
- Perform experiment 10 times; show worst, median, best
- Note: Log Y axis
- Linear TTFR until about 85-90 tags, then exponential
- Last few tags sometimes unreadable



- ~115 Class 0 tags
- Exponential past ~70 tags
- Much faster than Class 1



Tag Read Rates in Population

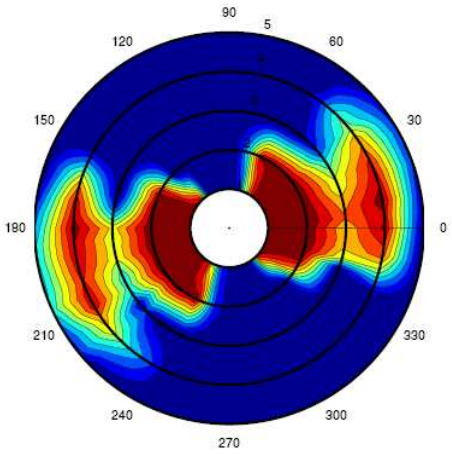


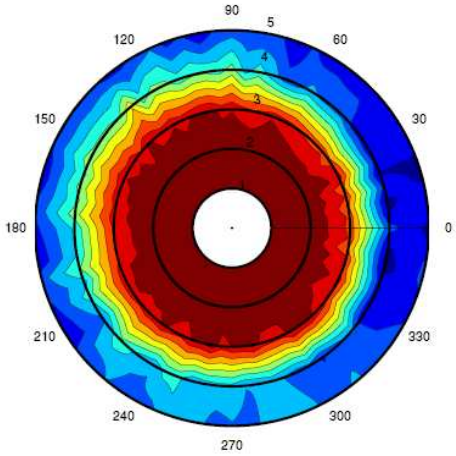
- Speculate:
  - Class 0 & Class 1 tags all weak-in-field
  - ~2/3 Pharma strong-in-field
- Class 0 scales much better than Class 1

Tagging Cell Phones?

- Client wants access control
  - No phones in restricted area
  - Wants to identify, not EAS
  - Leverage towards other projects
- Question: Can you put RFID tags on cell phones?

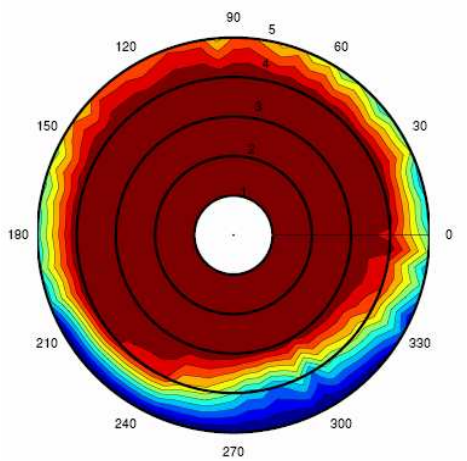
Response Rate vs. Distance, Orientation

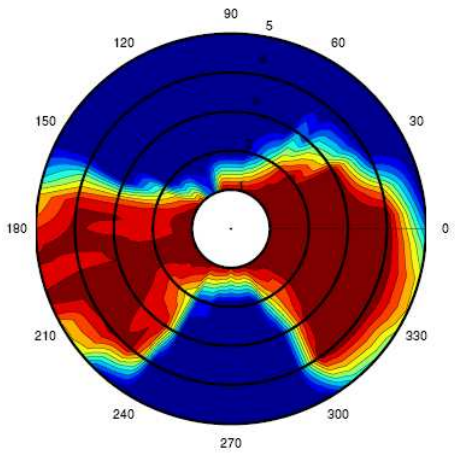




- Tag in free space is ok
  - readable to 3-4 feet.
  - Nulls in E-plane are large
  - Form factor can fit on ~50% of phones tested
  - Metalic paint = 0 performance

Response Rate vs. Distance, Orientation





- Tag on Nokia 3360: full of surprises
  - Performance *improves*
  - Radiation patterns for E and H planes reverse
- Speculate: tag coupling with phone antenna
- Client not content with performance

Research Directions

- Protocols
- Antennas
- Security
- Circuits

- Scalability
- Testing
- Information management

- Gen 2 still “dumb”
- Metal, water, 10% BW
- Use with DOD, DOE?
- Reduce power
- Impedance matching
- Gen 1 Class 0 scales
- Radios
- Schemas, databases, filtering, machine learning

Questions?